

*TIMING, REMEMBERING, AND DISCRIMINATION*

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Four pigeons were first trained in a timing procedure. In one condition, each trial began with the presentation of an X on the center key, followed by a delay (short or long), after which two side keys were lit. If the delay was short, pecks to the red side key were reinforced. If the delay was long, pecks to the green side key were reinforced. In a second condition, the opposite contingencies applied following presentation of a square on the center key. Choice responses were then tested at 10 time intervals ranging from short to long (1 to 4 s and 4 to 7 s in different conditions). The two timing conditions were combined to create a remembering condition in which correct responding depended upon discrimination of both the sample stimulus (X or square) and the delay interval (short or long). Choices varied systematically across delay in timing conditions, but in remembering conditions, accurate choice at the training delays did not initially generalize to intermediate delays. However, with prolonged training in the remembering task, the response pattern began to resemble that of the timing conditions. Generalization gradients were asymmetrical, in accordance with Weber's Law, in that greater generalization occurred with longer delays than with shorter delays.

*Key words:* remembering, timing, discrimination, generalization, delayed-symbolic-matching to sample, key peck, pigeon

Both timing and remembering involve the common element of the passage of time. In this article we describe the results of a novel task that suggest that in memory procedures the delay interval can serve as a discriminative stimulus. In timing experiments, a time interval is the discriminative stimulus. In some timing procedures, reinforcers follow responses made on one manipulandum for the first half of a trial and responses on another manipulandum for the second half of a trial (e.g., Bizo & White, 1994, 1995, 1997; Machado & Guilhaudi, 2000). In other timing procedures, responses to different manipulanda after signals of different lengths are reinforced (e.g., Church & Deluty, 1977; Machado & Keen, 1999). Psychophysical functions, which plot the proportion of responses on one manipulandum as a function of time, demonstrate the extent of discriminative control.

In remembering experiments, such as delayed matching-to-sample (DMTS) (Blough, 1959), the discriminative response follows the discriminative stimulus after a delay. A sample stimulus is presented prior to a delay interval. After the delay interval, a response to a choice stimulus that matches the sample is reinforced. Although the sample is the discriminative stimulus, the delay interval also can gain discriminative control and is part of a compound discriminative stimulus (Sargisson & White, 2001; White, 2001, 2002).

The usual DMTS training procedure begins with no delay between the presentation of the sample and comparison stimuli. Delays are introduced gradually and the result is a decrease in matching accuracy as the delay increases. Sargisson and White (2001), however, trained different groups of pigeons on a DMTS task with a single delay of either 0, 2, 4 or 6 s from the outset of training. When tested with a range of delays, rather than matching accuracy decreasing with increasing delay, accuracy was highest at the original training delay, even when this delay was longer than test delays. White and Cooney (1996) also showed that the delay interval forms part of the discriminative stimulus in a DMTS task. When choice responses were differentially reinforced at one delay but not another, response bias, or the tendency to respond on

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the comparison stimulus associated with the higher rate of reinforcement, was specific to that delay and did not generalize to the other delay. In another experiment, White (2002) showed that accuracy with a single delay in a range of delays decreased when responses were no longer reinforced after that delay. White's (2002) result demonstrated the occurrence of delay-specific remembering because accuracy was reduced at a single delay relative to shorter and longer delays.

Although the studies by Sargisson and White (2001), White and Cooney (1996), and White (2001, 2002) have shown that the delay in DMTS may serve as a discriminative stimulus, the delay interval is not usually arranged as a discriminative stimulus in memory tasks. Some researchers have attempted to make the delay interval more salient. For example, Wasserman, Grosch, and Nevin (1982) and MacDonald and Grant (1987) signaled the length of the upcoming delay by superimposing a symbol onto the sample stimulus. MacDonald and Grant showed that choice accuracy of pigeons was lower after the longer of two delays. When the cues for short versus long delays were reversed, accuracy increased after the long delay, and decreased after the short delay, showing that performance can be specific to different delays.

Other researchers have examined the influence of the delay interval, for example, by increasing the number of trials with long delays in human (Anderson, Tweney, Rivardo, & Duncan, 1997) and animal (Sargisson & White, 2004) short-term memory tasks or by manipulating the distribution of delay intervals (Carter & Werner, 1978; Honig, 1987; Honig & Dodd, 1986; Honig & Wasserman, 1981). In these studies, changing the distribution of delay-interval duration influenced remembering performance despite the fact that discrimination of delay was not a procedural requirement (Sargisson & White, 2004).

In the present experiment, the delayed symbolic-matching-to-sample (DSMTS) task required discrimination of the duration of the delay interval for matching to be accurate. That is, the pigeons were unable to perform the task accurately unless they responded on the basis of both the sample and choice stimuli and the delay-interval duration, thereby estab-

SAMPLE	X		■	
	short	long	short	long
CORRECT	R	G	G	R
ERROR	G	R	R	G

Fig. 1. Matrix of correct and incorrect red and green responses given X- and square-sample stimuli at short and long delays.

lishing the delay interval as a discriminative stimulus, as in timing tasks.

Four pigeons were first trained in two separate timing tasks (the *timing* conditions). These timing tasks were then combined to create a DSMTS task (the *remembering* condition). In both conditions, a response to the red choice stimulus was correct following the X sample when the delay interval was short, and following the square sample when the delay interval was long. A response to the green choice stimulus was correct following the X sample when the delay interval was long and following the square sample when the delay interval was short (see Figure 1). In the timing condition, sessions with the X sample were conducted separately from sessions with the square sample. In the remembering condition, trials with X and square samples were mixed within sessions. Thus the important elements in the conditional discrimination were the sample (X or square), delay duration (short or long), and choice stimulus (red or green). The task therefore required delay-specific remembering.

After training with both the timing and remembering conditions, test trials in probe sessions were conducted in which choices were recorded after the training delays and eight intermediate delays. This generalization test, conducted in extinction, examined the extent to which delay-specific remembering generalized to intermediate delays. Three training conditions were run separately with short and long intervals of 1 and 4 s (short-delay set), and then 4 and 7 s (long-delay set), then the condition using the short-delay set was replicated with 3 of the 4 pigeons.

The design of this experiment enabled a comparison of timing and remembering in

terms of discriminative control by delay-interval duration. The remembering task was expected to be more difficult for the pigeons than the timing task, because it required a more complex conditional discrimination. But the interesting question was whether the delay interval would have similar effects in both task types. Typically, in timing experiments, such as the one reported by Machado and Keen (1999), the probability of responding on the manipulandum associated with the longest interval increases as the interval lengthens. Obtaining similar results in the DSMTS task to those obtained in the timing procedure would show generalization of responses from trained delays to intermediate delays as in Sargisson and White (2001).

## METHOD

### *Subjects*

Four pigeons, numbered R1, R2, R3, and R5, aged between 3 and 5 years, were individually housed in wire cages measuring 400 mm deep, 500 mm high and 400 mm wide with free access to water and grit. The pigeons were weighed daily and maintained at  $85\% \pm 10$  grams of their free-feeding weights through postexperimental feeding of a mixture of wheat, corn, peas, and pellets. If a pigeon's weight fell outside the range, it was excluded from experimental sessions until its weight was within the range. All pigeons had had some limited experience with delayed matching-to-sample tasks, and had been trained to peck white response keys for wheat reinforcement.

### *Apparatus*

Four Med Associates Inc. chambers were used, measuring 295 mm high, 295 mm wide, and 245 mm deep. The walls of the chambers were made of black plastic. Three translucent plastic response keys, 21 mm in diameter, were recessed 10 mm into the front panel of each chamber, 210 mm from the grid floor and 60 mm apart. All three keys could be illuminated red, green, or white. A white X on a black background and a black square on a white background could be presented on the center key. The keys required a force of at least 0.15 N to be operated. A hopper situated behind an aperture 125 mm below the center key pro-

vided access to wheat when raised. The hopper was illuminated with a 1-W white bulb when raised. A computer linked to the chambers via a Med Associates Inc. interface presented stimuli and recorded the pigeons' responses.

### *Procedure*

*Timing with X sample.* In the first timing condition, each trial began with the center key illuminated with an X. Five pecks to the center key turned the keylight off and initiated a dark interval of either 1 or 4 s. After this interval, one side key was illuminated red and the other green. A peck to the red side key was deemed correct following the 1-s interval, as was a peck to the green side key following the 4-s interval (see Figure 1). Each trial was followed by an intertrial interval of 15 s, during which all keys were dark. For the first five trials, treated as warm-up, the color for each side key was selected randomly. The presentation of red and green on the side keys for the remaining 96 trials in each training session was constrained so that the two colors appeared equally often on each key in a quasirandom order.

Initially, every correct response produced 3-s access to wheat. After 10 training sessions for Pigeons R1, R3, and R5, and 19 training sessions for R2, the probability of reinforcement for correct responses was reduced to .5. Nonreinforced correct responses were not signaled but instead resulted in the same outcome as for incorrect responses, namely a 3-s blackout during which all keys were dark, followed by the intertrial interval. After nine training sessions with a reinforcer probability of .5 for Pigeons R1, R3, and R5, and two training sessions for R2, the first probe session was conducted (see below).

*Timing with square sample.* Following four probe sessions with the X stimulus, the center-key stimulus was changed to a square. The procedure was the same as for the X except that a single response to the green comparison was correct following the 1-s delay and a response to the red comparison was correct following the 4-s delay (see Figure 1). After 11 training sessions for Pigeons R1 and R3, 12 training sessions for R5, and 14 training sessions for R2, the reinforcer probability was reduced to .5. After six training sessions with a reinforcer probability of .5 for Pigeons R1

Table 1

Number of sessions conducted with each pigeon for the X and the square (■) stimulus. Training totals include all sessions prior to the commencement of probe sessions.

Condition	Pigeon	Training (X)	Probe (X)	Training (■)	Probe (■)	Training (X■)	Probe (X■)
Short-delay set	R1	19	4	17	4	77	10
	R2	21	4	18	4	102	11
	R3	19	4	15	4	74	10
	R5	19	4	18	4	91	10
Long-delay set	R1	44	4	67	4	117	10
	R2	46	4	124	4	71	10
	R3	26	4	36	4	94	10
	R5	32	4	59	4	171	2
Short-delay-set replication	R1	6	4	8	4	9	10
	R2	9	5	14	4	6	10
	R3	14	5	14	4	12	10

and R5, and four training sessions for Pigeons R2 and R3, the first probe session was conducted.

Response accuracy was not affected by the reduction of reinforcer probability in any condition (data not shown). Table 1 gives the order of conditions and the number of sessions completed by each pigeon.

*Probe sessions.* Probe sessions were conducted only if the proportion correct in the preceding training session was at least .8 (.7 for Pigeon R3) with the shortest delay. Probe sessions were similar to training sessions except that each session contained 120 trials. On 60 of these trials (training trials), the original training delay durations of 1 and 4 s were used, with every correct response producing access to wheat. The remaining 60 trials (test trials) comprised six trials each with test delays of 1, 1.33, 1.66, 2, 2.33, 2.66, 3, 3.33, 3.66, and 4 s. Responses on these trials were not reinforced and instead resulted in a 3-s blackout. Training and test trials were mixed randomly within the probe session. Four probe sessions were conducted for both the X- and the square-sample stimuli, and one training session was conducted after each probe session.

*Remembering conditions.* After completing four probe sessions with the square sample, DSMTS training began for all pigeons. Of the 97 trials per session in this condition, 49 trials began with the presentation of the square sample stimulus and 48 with the X in a quasirandom order that ensured that each sample was not presented more than five consecutive times. Reinforcement contingencies for responses to red and green side keys

following presentation of the X or square sample after 1- or 4-s delays were the same as in previous conditions (Figure 1). All incorrect responses resulted in a 3-s blackout.

After a minimum of 60 training sessions with a reinforcer probability of 1.0, the reinforcer probability was reduced to .5 for all pigeons. Probe sessions were conducted for each pigeon only if proportion correct in the preceding training session, averaged over both trial types (X and square), was at least .8 (.7 for Pigeon R3). A minimum of one training session was conducted between each probe session. Ten probe sessions were conducted with Pigeons R1, R3, and R5. Pigeon R2 completed 11 probe sessions because it did not complete all 120 trials in each probe session. Remembering probe sessions used the same 10 test delays as in previous probe sessions for both sample stimuli. As in the probe sessions for the timing conditions, each remembering probe session contained 120 trials (60 training and 60 test trials). On the 60 training trials (30 with each sample stimulus), the training delays of 1 and 4 s were used, with every correct response reinforced. The 60 test trials comprised six trials (three with each sample) with each of the 10 test delays. Responses were not reinforced on these trials.

*Long-delay-set conditions.* Once all pigeons had completed the last probe session in the first remembering condition with delays of 1 and 4 s, all timing and remembering conditions were repeated but with delays of 4 and 7 s. Delays of 4 and 7 s were chosen because they have the same range as 1 and 4 s, and, therefore, performance would not be con-

founded by different ranges of delays. As with the previous conditions, following the X sample, a peck to the red stimulus was correct following the shorter of the two delays (4 s) and a peck to the green key correct following the presentation of the longer of the two delays (7 s). Following the square sample, the reverse was true. Once the reinforcer probability had been reduced to .5, probe sessions were run on an individual basis for each pigeon (based on the stability criterion above) using delays of 4, 4.33, 4.66, 5, 5.33, 5.66, 6, 6.33, 6.66 and 7 s. Table 1 shows the number of training sessions completed by all pigeons prior to the commencement of probe sessions with the long-delay set. The data for Pigeon R5 were included in the analyses but after this pigeon completed two probe sessions in the remembering condition, it failed to reach the criterion for further probe sessions. Therefore, remembering probe sessions with the long-delay set for Pigeon R5 are made up of fewer trials than for the other pigeons.

*Replication of short-delay-set conditions.* After completing 10 probe sessions in the remembering conditions with the long-delay set, all short-delay conditions were replicated for Pigeons R1, R2, and R3. Pigeon R5 continued working in the long-delay-set remembering condition, but as it never completed this condition, it did not participate in the replication of the short-delay set. All aspects of the replicated conditions were identical to the original short-delay conditions. The number of training and probe sessions completed by Pigeons R1, R2, and R3 are shown in Table 1.

*Continuous remembering condition.* Upon completion of the replication of the short-delay-set conditions, the procedure was changed so that a remembering probe session with the short-delay set was conducted daily. All aspects of the probe sessions were identical to probe sessions run earlier. Pigeons R1, R2, R3, and R5 participated in 125, 125, 119, and 123 probe sessions, respectively.

## RESULTS

### *Timing and Remembering with Both Delay Sets*

Responses from all pigeons during each probe session in each condition were summed. Summed responses for training and test trials within the probe sessions are shown separately

for the short-delay set and the long-delay set in Appendices A and B, respectively.

Choice responses were converted to a discriminability measure,  $\log d$ , using:

$$\log d = 0.5 \log \left( \frac{X_r}{X_g} \cdot \frac{S_g}{S_r} \right) \quad (1)$$

where  $X_r$  and  $S_r$  are choices of red following X and square (S) samples, and  $X_g$  and  $S_g$  are choices of green following X and square samples. Equation 1 is based on the discriminability measure described by Davison and Tustin (1978), namely the log of the geometric mean of the ratio of correct to error responses. Because correct choices with the short delay are red following X and green following square, high discriminability with the short delay is given by a large positive value of  $\log d$ . Because correct choices with the long delay are green following X and red following square, high discriminability with the long delay is given by a large negative value of  $\log d$ . The greater the absolute value of  $\log d$ , the higher the discriminability. A  $\log d$  value of zero indicates chance responding. For the present data, 0.25 was added to all cells (as recommended by Brown & White, 2005) to prevent infinite  $\log d$  values.  $\log d$  was calculated separately for training trials and for test trials conducted during probe sessions.

Figure 2 shows  $\log d$  for training trials completed during probe sessions for each pigeon. High discriminability is shown by high absolute  $\log d$  values. Thus, the steeper the line, the greater the discriminability of the stimuli. Discriminability was highest with the timing short-delay set (filled circles) for all pigeons, although minimally so for Pigeon R2. Usually, the shallowest lines were produced in the remembering conditions (open symbols), with the line for the long-delay set (open triangles) being overall shallower than that for the short-delay set (open circles). The mean plots (Figure 2, bottom panel) show that the lines for the timing conditions (filled symbols) were steeper than those of the remembering conditions (open symbols), and that the short-delay set (circles) produced steeper lines than the long-delay set (triangles). A two-way analysis of variance on the slopes showed a significant effect of condition (timing vs.



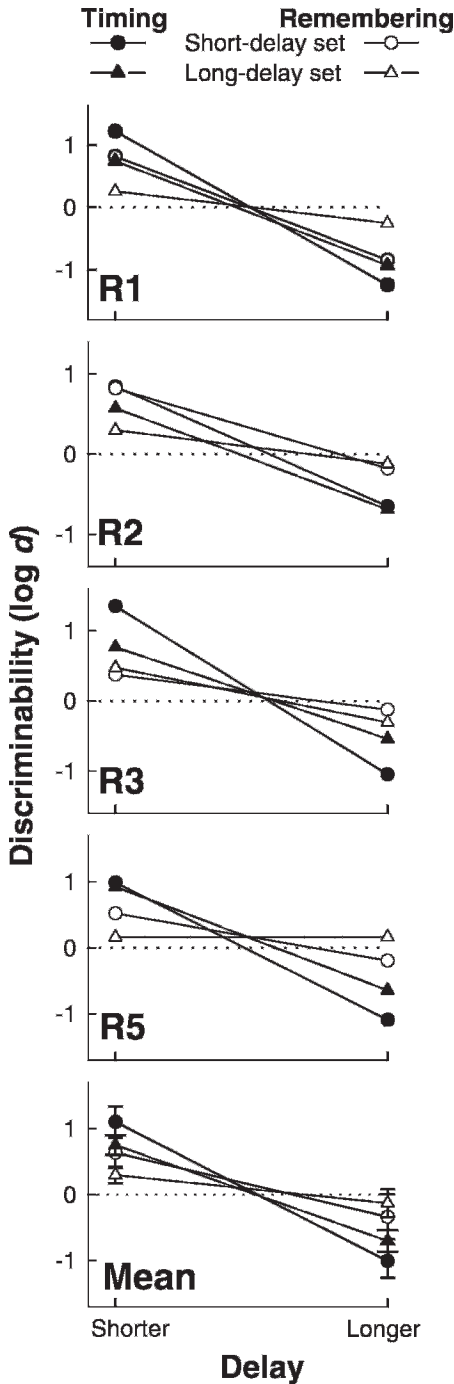


Fig. 2. Discriminability ( $\log d$ ) for training delays for timing (filled symbols) and remembering (open symbols) with the short-delay set (circles) and long-delay set (triangles) during probe sessions for each pigeon and for the mean across pigeons. Error bars represent the standard deviation across pigeons.

remembering) on slope ( $F(1, 3) = 40.15$ ,  $p = .008$ ), with the mean slope for timing ( $-0.59$ ) being steeper than that of remembering ( $-0.23$ ). There was also a significant effect of delay set (short vs. long) on slope ( $F(1, 3) = 20.03$ ,  $p = .02$ ), with the mean slope for the shorter set ( $-0.51$ ) being steeper than that of the longer set ( $-0.31$ ). There was no significant interaction between condition and delay set ( $F(1, 3) < 1.0$ ), suggesting that while the remembering condition was overall more difficult than the timing condition (shown by a shallower slope), lengthening the delays attenuated accuracy to the same degree in both conditions.

For test trials, discriminability for timing with the short-delay set (Figure 3, left panel, circles) was higher with the shortest and longest delay for all pigeons than with the long-delay set (Figure 3, left panel, triangles), although  $\log d$  was only slightly higher for the shortest delay in the short-delay set than the long-delay set for Pigeon R3.  $\log d$  decreased between the shortest and longest delay in both conditions, but was closer to zero at almost all delays with the long-delay set.

In the remembering condition with the short-delay set (Figure 3, right panel, circles),  $\log d$  with the 1-s delay was close to 1 (0.89, 1.23, 0.68, and 0.80 for Pigeons R1, R2, R3, and R5, respectively). For Pigeons R2, R3, and R5  $\log d$  values for all intermediate delays were close to zero with absolute  $\log d$  at the 4-s delay (0.69, 0.09, 0.48, and 0.34) lower than at the 1-s delay. Pigeon R1's response pattern with the short-delay set in the remembering condition was similar to that in the timing conditions, in that  $\log d$  decreased from shortest to longest delay, except that the curve was flatter (Figure 3, right panel). Absolute  $\log d$  values in the remembering condition with the long-delay set (Figure 3, right panel, triangles) were higher than zero at the extreme delays and close to zero for all intermediate delays. For Pigeons R2, R3, and R5, there was little difference between the  $\log d$  values for the two remembering conditions, suggesting that increasing the delays did not necessarily increase the difficulty of the task in remembering trials.  $\log d$  values with the long-delay set in the remembering condition for Pigeon R1 were similar to those for the other pigeons.

The plots in the bottom panels of Figure 3 show that the mean  $\log d$  values for the timing

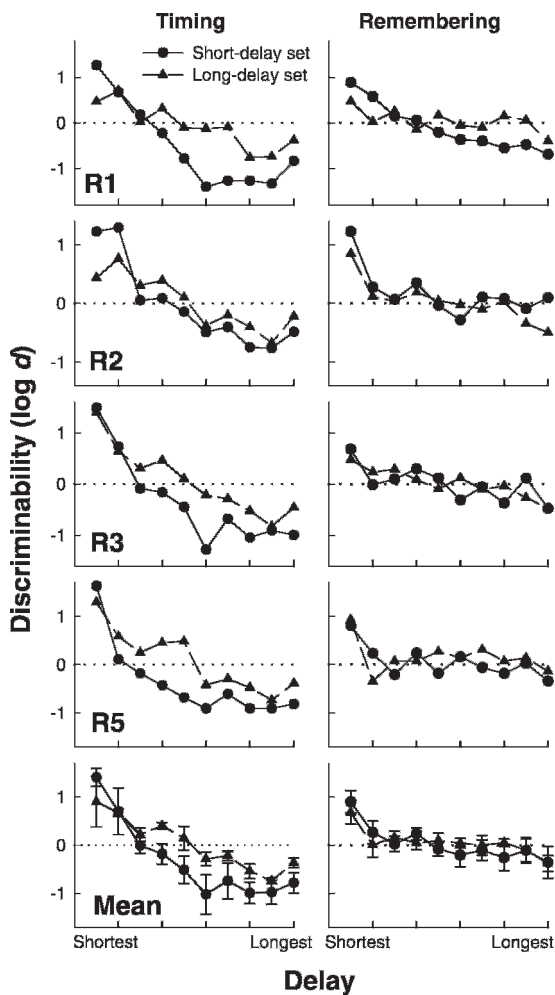


Fig. 3. Discriminability ( $\log d$ ) for test delays for timing (left panel) with the short- (circles) and long-delay set (triangles), remembering (right panel) with the short- (circles) and long-delay sets (triangles) for all pigeons and for the mean across pigeons. Error bars represent the standard deviation across pigeons.

conditions decreased as a function of increasing delay, with a steeper decline for the short-delay set. Absolute mean  $\log d$  values at the extreme delays were higher in the timing conditions (left panel) than in the remembering conditions (right panels), and the pattern of variation in  $\log d$  was also very different in these two conditions. In the remembering conditions, mean  $\log d$  was close to 1.0 (0.90 and 0.68) at the shortest delays for both delay sets, and remained close to zero for all intermediate delays. The longest delay in both remembering conditions produced mean  $\log$

$d$  values below zero ( $-0.35$  with 4 s and  $-0.38$  with 7 s).

For the test data for each pigeon, a straight line was fitted to the  $\log d$  values for the intermediate delays (i.e., excluding the shortest and longest delays). A two-way analysis of variance showed a significant effect of condition (timing vs. remembering) on slope ( $F(1, 3) = 2741.82$ ,  $p = .000$ ; the unusually high  $F$  value is explained by the absence of overlap in the data), with the mean slope for the timing conditions ( $-0.62$ ) being steeper than that for the remembering conditions ( $-0.12$ ). There was no significant effect of delay set on slope ( $F(1, 3) = 1.55$ ,  $p = .30$ ) and no significant interaction between condition and delay set ( $F(1, 3) < 1.0$ ). Similar results were obtained from a two-way analysis of variance using the slopes of linear functions fitted to all delays. Slopes were generally steep for timing conditions, shallow for remembering conditions, and this pattern was the same for both delay sets.

#### Replication of Short-Delay Set Conditions

Discriminability ( $\log d$ ) for timing and remembering in the replication of the short-delay-set conditions for Pigeons R1, R2, and R3 (not shown) was similar to that obtained in the first short-delay-set conditions. There were no statistically significant differences between the  $\log d$  values for the replication and the first timing and remembering conditions for either training or test trials (as shown in separate three-way analyses of variance for training and test data). All raw data are in Appendix C.

#### Continuous Remembering Condition

The last 10 sessions, of a minimum of 119, of the extended continuous remembering condition for each pigeon were used for data analysis. All raw data for these 10 probe sessions are in Appendix D. Figure 4 shows discriminability ( $\log d$ ) for training trials (left panel) and test trials (right panel) for all pigeons, and for the mean across pigeons, for the first timing condition, the first remembering condition, and the continuous remembering condition. All three conditions shown in Figure 4 used the short-delay set. Recall that in the first timing condition, the X and square sample stimuli were presented separately in different conditions; the X and square were

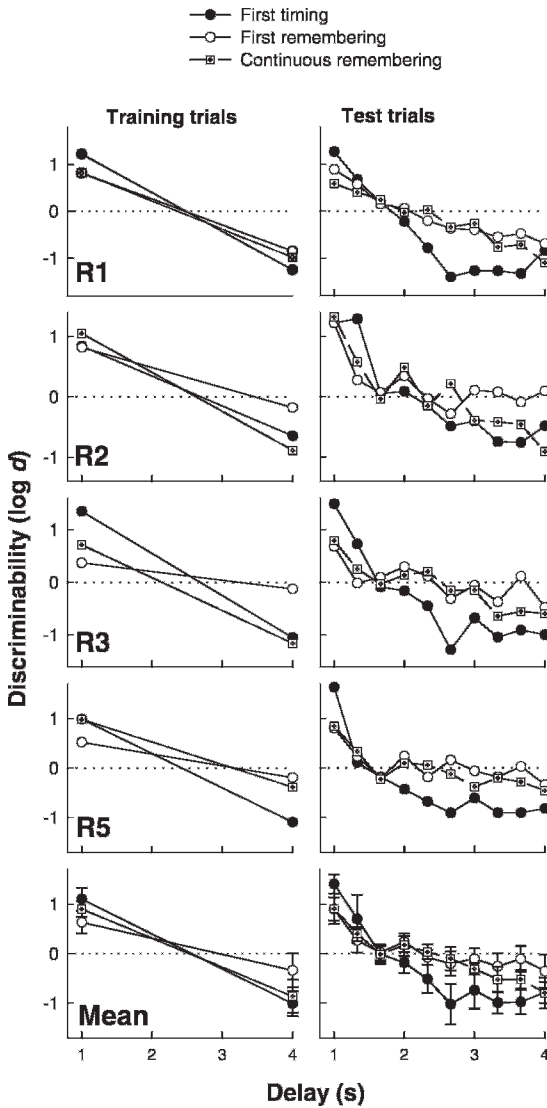


Fig. 4. Discriminability ( $\log d$ ) for training (left panel) and test trials (right panel) for the first timing condition (filled circles), first remembering condition (open circles), and the continuous remembering condition (squares) for all pigeons and for the mean across pigeons. Error bars represent standard deviation across pigeons.

combined within sessions in the first remembering condition; and in the continuous remembering condition, remembering probe sessions were conducted daily.

For training trials for all pigeons (Figure 4, left panel), the slope of the function connecting  $\log d$  values for the 1- and 4-s delays steepened following continuous remembering sessions (squares) compared to the first re-

membering condition (open circles). For Pigeon R2, the slope for the continuous remembering condition ( $-.65$ ) was not only steeper than that of the first remembering condition ( $-.33$ ), but was also steeper than the slope of the first timing condition (filled circles,  $-.50$ ). A one-way analysis of variance showed that there was a significant effect of condition on slope values for training trials ( $F(2, 6) = 8.47, p = .02$ ). An LSD posthoc test showed that the mean slope for timing ( $-.70$ ) differed significantly from the mean slope for remembering ( $-.32, p = .007$ ). The mean slope for continuous remembering ( $-.58$ ), however, differed significantly only from that of the earlier remembering condition ( $p = .03$ ) and not from the mean slope of the timing condition ( $p = .25$ ).

In test trials (Figure 4, right panel),  $\log d$  values at delays shorter than 3 s for the continuous remembering condition remained similar to those of the first remembering condition. With delays longer than 3 s, absolute  $\log d$  values increased relative to those of the first remembering condition. Thus, discriminability improved with longer delays in the continuous remembering condition, but not with shorter delays.

A one-way analysis of variance showed a significant difference between the slopes of straight lines fitted to  $\log d$  values for intermediate delays in the three conditions ( $F(2, 6) = 47.96, p = .0002$ ). An LSD posthoc test confirmed that all three means differed significantly from one another, with mean slopes of  $-0.67$  for the first timing condition,  $-0.37$  for the continuous remembering condition, and  $-0.18$  for the first remembering condition. Similar results were obtained from a one-way analysis of variance using slopes of linear functions fitted to all 10 delays.

Overall, the results from the continuous remembering condition showed that with continued exposure to the test delays in the remembering condition, the response pattern became more similar to that seen in the timing condition with the longer delays in the set, although accuracy with shorter delays did not improve beyond that in the first remembering condition.

Nine sets of 10 sessions occurring at equal intervals from the first to the last continuous remembering session were selected to determine whether performance had stabilized. The absolute  $\log d$  values for each delay in



each of the nine sets were subtracted from those of the preceding set to obtain eight sets of differences. The mean absolute difference for each set was calculated and plotted on a chronological scale. The plots and the variance around the mean points (not shown) indicated that the differences were stable for Pigeons R3 and R5, but were still decreasing for Pigeons R1 and R2, showing that performance had not yet stabilized for 2 of the 4 pigeons.

## DISCUSSION

For all pigeons, high discriminability was seen with both short and long delays during probe sessions in the timing conditions (Figure 3, left panel), with reduced discriminability at intermediate delays. When the pigeons were only required to time the interval, choices progressively shifted toward the longer of the two extreme delays (i.e., red choices after square samples and green choices after X samples) as the time interval increased. This finding was consistent with the findings of Machado and Keen (1999), whose procedure was similar to the timing procedure in the present experiment.

In the remembering conditions with both delay sets,  $\log d$  was close to zero with intermediate delays and close to 1.0 for the shortest delay in each set (Figure 3, right panel). This finding is consistent with that of Sargisson and White (2001) who found that choice responses made in a standard DMTS task after nontrained delays were less accurate than those made following specifically trained delays. Unlike the findings of Sargisson and White, remembering did not appear to generalize to untrained delays in the first remembering condition. Instead, red and green choices made at intermediate delays were randomly distributed ( $\log d$  values close to zero), even with delays only slightly shorter or longer than trained delays. Thus, the pattern of responding produced in remembering conditions differed from that for timing. However, the remembering task was more difficult than the timing task because it involved the additional discrimination of the sample stimulus. Possibly, the low overall accuracy seen in the remembering condition masked any generalization, especially with the longest delay. That is, with  $\log d$  values close to zero with the longest delay in each remember-

ing set, generalization to similar delays would be seen as zero  $\log d$  values. The continuous remembering condition was conducted to determine whether further exposure to the remembering condition would improve accuracy, increase generalization to intermediate delays, and produce a pattern of responding more similar to that of the timing condition.

The continuous remembering condition increased discriminability at both delays in the training trials (Figure 4, left panel) relative to the first remembering condition. For test trials (Figure 4, right panel), absolute  $\log d$  increased relative to the first remembering condition for all delays longer than 3 s, but was unchanged with shorter delays. Accuracy increased with longer delays, but it did not reach the level seen in the first timing condition. The data for 2 of the 4 pigeons had not yet stabilized after 125 sessions, however, so it is possible that accuracy might have improved with further training.

On the basis of a comparison of the results from the first timing, first remembering, and continuous remembering conditions, the most appropriate conclusion is that the difference between timing and remembering is quantitative, not qualitative. That is, remembering is more difficult than timing, but it is not fundamentally different. Both tasks require a conditional discrimination and the common element is the discrimination of delay duration. Two key results support the conclusion of a quantitative, rather than qualitative, difference between the two tasks. Firstly, in Figure 4 (right panel) the test data for the continuous remembering condition are similar to those of the first timing condition for Pigeon R2. This shows that when the same level of accuracy is reached in both timing and remembering conditions, the pattern of responding is similar. Secondly, accuracy after more than 100 sessions improved for all pigeons, albeit more quickly for some than for others. If timing and remembering were qualitatively different, we would have no reason to expect that all pigeons would show a similar trend. Instead, it would be equally likely for the accuracy of some pigeons' responses to have decreased relative to the first remembering condition. That is, given a qualitative difference between timing and remembering, greater exposure to the remembering task could have flattened some pigeons' generalization

functions, and steepened others. Instead, the slopes of straight lines fitted to test data for the continuous remembering condition were becoming steeper for all pigeons, and therefore more like those of the timing condition. So, the addition of a remembering component to the timing task increased the difficulty of the task, but the difference between tasks appeared to be quantitative, not qualitative.

A clear outcome of the test trials for the timing conditions was that the discriminability functions were steeper at short delays than at long delays. This result is consistent with the application of Weber's Law (Weber, 1834/1978) to timing data from previous studies (Killeen & Weiss, 1987). Weber's Law states that the perceptual variance of a stimulus is proportional to its overall magnitude. That is, for timing, there is greater generalization between overall long delays than between overall short delays. The present result suggests that Weber's Law also applies for remembering. That is, discriminability at short delays was greater than at long delays and, further, there was greater generalization of performance across delays at the long training delay than at the short training delay. This conclusion further reinforces the treatment of remembering as involving the discrimination of delay duration.

In conclusion, the present remembering procedure required different discriminations at the different delays. In the continuous remembering condition, the discrimination was clearly achieved, showing that remembering can be specific to a delay. Generalizing this conclusion to standard DMTS procedures, the present result suggests that delay may be discriminated in memory procedures. Stimulus control, therefore, is influenced by delay just as it is by other stimulus variables.

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## APPENDIX A

Red and green choices for each pigeon following square and X samples summed across probe sessions for timing and remembering with the short-delay set.

		R1								R2				R3				R5			
		Sq				X				Sq		X		Sq		X		Sq		X	
		Delay (s)		R	G	R	G	R	G	R	G	R	G	R	G	R	G	R	G	R	G
Timing	Training	1	8	108	111	5	12	94	95	15	3	113	104	7	14	102	108	8			
		4	117	7	6	118	89	21	20	96	114	9	11	113	108	16	5	119			
	Test	1	1	23	23	1	0	24	18	6	0	24	22	2	0	24	23	1			
		1.33	4	20	20	4	0	21	19	4	2	22	18	6	12	12	15	9			
		1.66	8	16	13	11	7	13	9	13	8	16	6	18	14	10	9	15			
		2	17	7	11	13	7	14	9	12	10	14	6	18	16	8	5	19			
		2.33	22	2	5	19	15	9	11	13	15	9	4	20	20	4	4	20			
		2.66	24	0	3	21	18	5	6	17	19	5	0	24	22	2	3	21			
		3	23	1	1	23	17	3	9	11	20	4	4	20	15	9	2	22			
		3.33	23	1	1	23	18	2	4	16	21	3	1	23	22	2	3	21			
		3.66	20	4	0	24	18	3	3	19	22	2	3	21	21	3	2	22			
		4	20	4	2	22	20	4	8	16	22	2	2	22	21	3	3	21			
	Training	1	12	128	129	31	31	100	139	10	39	101	109	51	37	103	128	32			
		4	132	28	12	128	93	51	56	71	95	65	63	77	83	77	43	97			
Remembering	Test	1	2	28	25	5	8	22	26	0	5	25	25	5	5	25	27	3			
		1.33	4	26	21	9	15	11	25	5	15	14	15	15	8	18	17	13			
		1.66	10	20	15	15	16	14	14	9	8	22	11	19	18	12	11	19			
		2	16	14	18	12	7	13	22	8	11	19	21	9	13	17	21	9			
		2.33	12	18	6	24	21	9	20	10	11	19	15	15	15	15	9	21			
		2.66	14	16	4	26	25	5	17	13	19	11	8	20	11	19	16	13			
		3	21	9	8	22	11	9	20	10	16	14	14	16	12	18	10	20			
		3.33	24	6	7	23	21	9	17	5	23	7	11	19	21	9	15	15			
		3.66	24	6	9	21	19	11	16	14	15	15	19	11	13	17	14	16			
		4	26	4	6	24	18	12	21	9	24	6	9	21	15	15	5	25			

APPENDIX B

Red and green choices for each pigeon following square and X samples summed across probe sessions for timing and remembering with the long-delay set.

		R1				R2				R3				R5				
		Sq		X		Sq		X		Sq		X		Sq		X		
		Delay (s)	R	G	R	G	R	G	R	G	R	G	R	G	R	G		
Timing	Training	4	21	88	96	13	26	97	87	23	13	98	87	19	16	86	96	7
		7	91	22	6	110	97	20	18	91	82	33	19	94	76	30	12	95
	Test	4	5	12	19	5	5	13	18	6	0	24	21	3	4	17	23	0
		4.33	2	18	16	5	3	18	25	4	5	23	22	5	8	16	24	3
		4.66	6	8	9	11	4	13	13	10	7	16	13	7	6	14	11	8
		5	12	8	14	2	4	21	12	10	3	18	12	8	8	12	17	3
		5.33	8	8	6	10	7	10	9	8	5	15	7	13	6	12	15	3
		5.66	10	7	7	9	8	6	3	14	14	10	8	16	13	8	4	18
		6	11	7	2	2	15	8	8	11	10	10	4	16	13	7	6	13
		6.33	19	1	5	11	17	8	5	16	15	5	4	16	17	3	7	12
6.66	15	3	2	14	15	1	7	13	17	6	1	20	16	4	2	17		
7	16	8	5	15	16	9	8	13	17	7	5	18	14	8	5	18		
Remembering	Training	4	43	88	90	56	38	75	90	45	39	94	117	32	10	16	16	12
		7	80	64	35	91	84	36	57	43	101	48	44	86	13	15	15	8
	Test	4	7	23	17	6	6	22	17	1	6	24	21	9	1	5	4	0
		4.33	13	11	17	13	13	7	22	7	11	19	19	11	3	1	2	4
		4.66	7	23	10	10	15	12	6	4	7	23	14	12	4	2	3	1
		5	14	6	16	14	8	11	19	11	5	15	10	20	1	3	2	4
		5.33	12	13	20	10	7	13	12	18	12	18	9	21	1	4	3	3
		5.66	16	14	14	16	13	7	18	11	10	20	14	16	2	4	3	3
		6	11	9	13	17	13	7	16	14	5	15	5	25	2	2	5	1
		6.33	18	12	15	5	20	10	14	6	15	15	10	12	4	2	3	1
6.66	14	14	17	13	16	2	12	8	21	9	12	18	2	4	3	3		
7	23	7	10	20	24	2	14	13	24	6	9	21	4	2	3	3		

## APPENDIX C

Red and green choices for each pigeon following square and X samples summed across probe sessions for the replication of timing and remembering with the short-delay set.

		Delay (s)	R1				R2				R3			
			Sq		X		Sq		X		Sq		X	
			R	G	R	G	R	G	R	G	R	G	R	G
Timing	Training	1	5	115	104	15	26	81	122	22	24	95	131	14
		4	98	22	12	109	90	13	43	97	106	15	13	142
	Test	1	2	22	22	2	3	19	27	3	3	21	28	2
		1.33	1	23	20	5	3	20	20	10	5	20	25	5
		1.66	12	12	15	9	8	12	18	12	13	11	16	14
		2	19	5	9	15	8	12	11	15	22	2	18	7
		2.33	18	6	10	13	7	16	9	21	19	4	3	17
		2.66	17	7	5	19	16	7	18	12	20	4	7	14
		3	22	2	2	22	12	8	12	13	23	1	1	8
		3.33	17	7	4	20	18	3	10	18	19	5	3	21
		3.66	19	5	3	21	18	4	4	26	21	3	1	24
		4	19	5	2	22	21	3	10	20	21	3	3	22
	Training	1	22	118	125	35	16	115	125	22	38	102	126	34
		4	111	49	38	102	111	32	46	83	110	50	51	89
	Test	1	3	27	25	5	5	25	24	2	4	26	28	2
		1.33	4	26	27	3	12	17	20	10	11	19	27	3
		1.66	14	16	24	6	10	20	20	4	12	18	15	15
		2	18	12	18	12	13	7	13	17	8	22	20	10
		2.33	19	11	11	19	19	11	16	14	14	16	11	19
		2.66	17	13	14	16	18	12	15	15	20	10	11	19
		3	17	13	12	18	10	10	23	7	20	10	7	23
		3.33	23	7	14	16	25	5	17	5	23	7	9	21
		3.66	23	7	15	15	24	6	16	14	18	12	16	14
		4	23	7	5	25	20	10	12	18	21	9	12	18

## APPENDIX D

Red and green choices for each pigeon following the square and X samples summed across the last 10 probe sessions in the continuous remembering condition.

		Delay (s)	R1				R2				R3				R5			
			Sq		X		Sq		X		Sq		X		Sq		X	
			R	G	R	G	R	G	R	G	R	G	R	G	R	G	R	G
Remembering	Training	1	19	121	140	20	5	118	120	21	30	110	141	19	9	131	138	21
		4	146	14	14	126	120	16	12	99	151	9	10	130	119	40	45	90
	Test	1	6	24	24	6	0	29	16	4	4	26	26	4	2	28	24	6
		1.33	7	23	20	10	3	20	21	9	15	15	23	7	8	22	19	11
		1.66	8	22	16	14	21	8	11	5	16	14	15	15	11	19	5	25
		2	14	16	13	17	5	15	23	7	19	11	23	7	10	18	14	16
		2.33	13	17	14	16	13	11	11	19	13	17	20	10	11	19	13	17
		2.66	18	12	7	23	9	19	17	13	21	9	16	14	13	17	9	21
		3	14	16	6	24	10	10	4	26	15	15	10	20	18	6	10	20
		3.33	28	2	8	22	17	13	3	17	27	3	9	21	17	13	10	20
		3.66	27	3	7	23	18	5	8	20	25	5	8	22	23	7	14	16
		4	28	2	2	28	21	7	1	28	25	5	7	23	25	5	11	19